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(71) Applicant : **RESEARCH DEVELOPMENT CORPORATION OF JAPAN**
5-2, Nagata-cho 2-chome
Chiyoda-ku Tokyo 100 (JP)

(72) Inventor : **Yokoyama, Masayuki**
MBS Haitzu B-201, 3-170 Shinmatsudo
Matsudo-shi, Chiba-ken (JP)

Inventor : **Sakurai, Yasuhisa**
17-6, Eifuku 3-chome, Suginami-ku
Tokyo (JP)

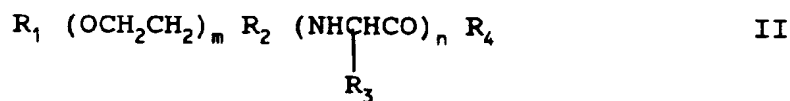
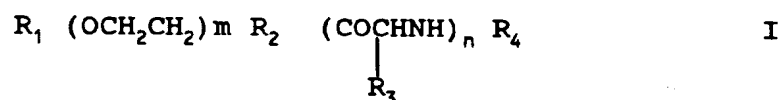
Inventor : **Okano, Teruo**
12-12, Kohnodai 6-chome, Ichikawa-shi
Chiba-ken (JP)

Inventor : **Kataoka, Kazunori**
Kashiwa-Biregge 141-9, Ohmuro 1083-4
Kashiwa-shi, Chiba-ken (JP)

(74) Representative : **Myerscough, Philip Boyd et al**
J.A. Kemp & Co. 14 South Square, Gray's Inn
London WC1R 5LX (GB)

(54) **Physical trapping type polymeric micelle drug preparation.**

(57) A polymeric micelle type drug comprises at least one hydrophobic drug physically trapped in a drug carrier comprising a block copolymer represented by formula I or II :



wherein R_1 is hydrogen or an alkyl group having 1 to 20 carbon atoms, R_2 is NH, CO, $R_6(CH_2)_qR_7$ (in which R_6 represents OCO, OCONH, NHCO, NHCOO, NHCONH, CONH or COO, R_7 represents NH or CO, and q is 1 to 6), R_3 is hydrogen, an alkyl group having 1 to 20 carbon atoms, $(CH_2)_pC_6H_5$, $(CH_2)_pCOOR_5$ or CH_2CONHR_5 (in which p is 1 or 2, R_5 represents a C_{1-20} alkyl group, a benzyl-substituted C_{1-20} alkyl group or a benzyl group), R_4 is hydrogen, hydroxyl, RCO-, RNH- or RO- where R is an alkyl group having 1 to 20 carbon atoms, m is 4-2500, and n is 2-300.

FIELD OF THE INVENTION

The present invention relates to drug carriers having hydrophilic and hydrophobic segments capable of physically trapping hydrophobic drugs, as well as to a polymeric micelle type drug having hydrophilic drugs physically trapped to said carrier.

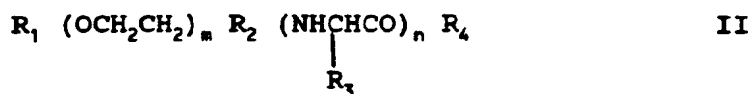
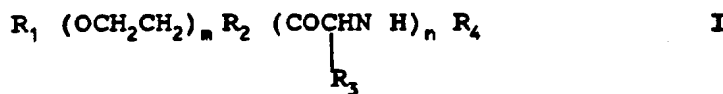
BACKGROUND OF THE INVENTION

A polymeric micelle type drug, in which a hydrophobic drug is chemically bound to a block copolymer through a covalent bond, was successfully constructed and applied by the present inventors for a patent in Japanese Patent Application No. 116,082/89. In spite of the fact that this prior polymeric micelle type drug is extremely superior as the means of administering a hydrophobic drug, the combination of hydrophobic drug and block copolymer is disadvantageously limited because its preparation requires functional groups for chemically binding a hydrophobic drug to a block copolymer.

Under the circumstances, however, no development has been made in a method of physically trapping hydrophobic drugs so as to incorporate them in the inner core of polymeric micelle or in a drug carrier for such a method.

The present inventors have tried to develop a physical trapping type polymeric micelle drug, in order to solve the above disadvantage of the chemical bond type polymeric micelle drug. The present inventors, as a result of their eager research, succeeded in preparing polymeric micelle type drug applicable to a wide variety of combinations of hydrophobic drugs and block copolymer by constructing a polymeric micelle from a drug carrier composed of a block copolymer having hydrophilic and hydrophobic segments and then permitting hydrophobic drugs to be physically trapped into the hydrophobic inner core of said micelle. The system for trapping drugs, developed by the present inventors, allows a wide variety of hydrophobic drugs to be easily incorporated in the polymeric micelle.

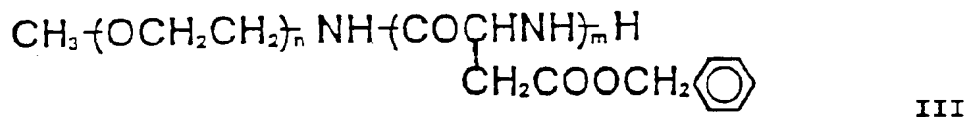
The present invention comprises a polymeric micelle type drug composition which comprises at least one hydrophobic drug physically trapped in a drug carrier comprising a block copolymer represented by formula I or II;



wherein R₁ is hydrogen or an alkyl group having 1 to 20 carbon atoms, R₂ is NH, CO, R₆(CH₂)_qR₇ (in which R₆ represents OCO, OCONH, NHCO, NHCOO, NHCONH, CONH or COO, R₇ represents NH or CO, and q is 1 to 6), R₃ is hydrogen, an alkyl group having 1 to 20 carbon atoms, (CH₂)_pC₆H₅, (CH₂)_pCOOR₅ or CH₂CONHR₅ (in which p is 1 or 2, R₅ represents a C₁₋₂₀ alkyl group, a benzyl-substituted C₁₋₂₀ alkyl group or a benzyl group), R₄ is hydrogen, hydroxyl, RCO-, RNH- or RO- where R is an alkyl group having 1 to 20 carbon atoms, m is 4-2500, and n is 2-300.

An alkyl group has from 1 to 20 carbon atoms and may be either straight chain or branched. Preferably the alkyl group has from 1 to 10 carbon atoms, for example 1, 2, 3, 4 or 5 carbon atoms.

According to a preferred embodiment the block copolymer is a compound represented by formula III:



wherein m is 4-2500 and n is 2-300.

According to a further preferred embodiment, the hydrophobic drug is adriamycin or indomethacin.

The present invention further provides a method for trapping hydrophobic drugs in drug carrier, which comprises the heating, ultrasonication or organic solvent treatment of hydrophobic drugs and drug carrier or formula I, II or III to physically trap said hydrophobic drugs in polymeric micelles comprising said drug carrier.

FIG. 1 shows particle size distribution by dynamic light scattering of polymeric micelles of polyethylene oxide-poly-(β -benzyl L-aspartate) block copolymer (A-5-10) in an aqueous solution.

FIG. 2 shows changes in fluorescence spectra of pyrene when incorporated in the inner core of polymeric micelle by heating. In the figure, Nos. 1-8 indicate the fluorescence spectra of pyrene at the respective concentrations of block copolymer.

FIG. 3 shows the amount of pyrene incorporated by three methods at various concentrations of block copolymer.

FIG. 4 is a gel permeation chromatogram (GPC) of adriamycin incorporated into polymeric micelles.

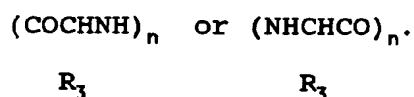
FIG. 5 is a gel permeation chromatogram of polymeric micelles.

FIG. 6 is a gel permeation chromatogram of adriamycin incorporated in micelles after allowed to stand for 5 hours in the presence of 50%(V/V) of fetal bovine serum.

FIG. 7 is a gel permeation chromatogram of 50%(V/V) fetal bovine serum.

Fig. 8 is a gel permeation chromatogram monitored at 312 nm at which indomethacin shows characteristic absorption.

The block copolymer comprises a hydrophilic segment and a hydrophobic segment. The hydrophilic segment comprises polyethylene oxide and the hydrophobic segment is represented by



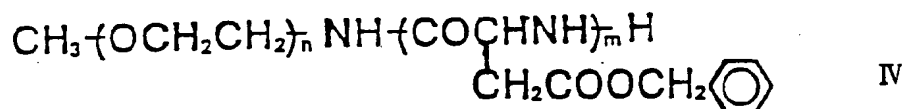
The hydrophobic segment comprises, for example, poly(β -benzyl L-aspartate), poly(γ -benzyl L-glutamate), poly(β -substituted aspartate), poly(γ -substituted glutamate), poly(L-leucine), poly(L-valine) or poly(L-phenylalanine).

The drug to be physically trapped in the hydrophobic inner core of polymeric micelle is not particularly limited. Examples are anticancer drugs such as adriamycin, daunomycin, methotrexate, mitomycin C, etc., painkilling and anti-inflammatory drugs such as indomethacin etc., drugs for the central nervous system, drugs for the peripheral nervous system, drugs against allergies, drugs for the circulatory organs, drugs for the respiratory organs, drugs for the digestive organs, hormones as drugs, metabolizing drugs, antibiotics, drugs for use in chemotherapy, etc.

The physical means of trapping hydrophobic drugs in polymeric micelles composed of the present drug carrier includes heating, ultrasonication and organic solvent treatment, which are conducted solely or in combination with one another. Heating is carried out at 30-100 °C for a period of time from 10 min. to 24 hours. Ultrasonication is carried out in the range of 1-200 W for a period of time from 1 second to 2 hours. The organic solvent used in organic solvent treatment is DMF, DMSO, dioxane, chloroform, n-hexane, toluene, methylene chloride, etc., which is used in the absence of water or after added in an amount of 0.01 % (v/v) or more to water.

Hereinafter, the present invention is specifically explained in detail with reference to the actual incorporation of adriamycin as an anticancer drug, indomethacin as a painkilling, anti-inflammatory drug and pyrene as a typical hydrophobic chemical, into an AB type block copolymer composed of a hydrophilic segment derived from a derivative of polyethylene oxide and a hydrophobic segment of poly(β -benzyl L-aspartate).

The compound of formula IV:



is polyethylene oxide-poly(β -benzyl L-aspartate) block copolymer consisting of polyethylene oxide and poly(β -benzyl L-aspartate) which have hydrophilic and hydrophobic properties, respectively. The compound of formula IV is compound of formula I wherein R₁ is a methyl group, R₂ is NH, R₃ is CH₂COOCH₂C₆H₅, and R₄ is

H.

This block copolymer is prepared by polymerizing, in the presence of an initiator, β -benzyl L-aspartate N-carboxy anhydride from the terminal primary amino group of polyethylene oxide (molecular weight of 200-250,000) having an amino group in one terminal and a methoxy group at the other terminal. The portion of poly(β -benzyl L-aspartate) in the block copolymer polyethylene oxide-poly(β -benzyl L-aspartate) may have a molecular weight varying from 205 to 62,000. By suitable selection of a chain length ratio of the two segments, this block copolymer forms a polymeric micelle with ethylene oxide as an outer shell and poly(β -benzyl L-aspartate) as an inner core. This polymeric micelle can stably incorporate hydrophobic pyrene, adriamycin and indomethacin by heating, ultrasonication, or treatment with organic solvent.

The drug carrier composed of the block copolymer according to the invention forms a stable polymeric micelle structure with which hydrophobic drugs can be incorporated very efficiently via physical trapping into the inner core. A drug difficult to administer into the living body owing to sparing water-solubility for its high hydrophobicity can be administered in the form of polymeric micelle type drug.

In addition, the invention does not require any functional group for chemical bonding and thereby enables a wide variety of combinations of hydrophobic drugs and polymeric micelle.

EXAMPLES

The present invention is described in detail with reference to the following examples, which however are not intended to limit the scope of the invention.

Example 1

β -benzyl L-aspartate N-carboxylic anhydride (1.99 g) was dissolved in 3 ml N,N-dimethylformamide, followed by addition of 15 ml of chloroform. Separately, 4.00 g of polyethylene oxide having methoxy group in one terminal and an amino group in the other terminal (molecular weight: 5,000) was dissolved in 15 ml chloroform, and the solution was then added to the above solution of β -benzyl L-aspartate N-carboxy anhydride. 26 hours thereafter, the reaction mixture was added dropwise to 330 ml diethyl ether, thereby giving rise to polymer precipitates which in turn were recovered by filtration, then washed with diethyl ether and dried under vacuum, to give polyethylene oxide poly(β -benzyl L-aspartate) block copolymer (referred to as "PEO-PBLA," hereinafter) (A-5-10). Yield was 5.13 g (91 %). The compositions of block copolymers thus synthesized are summarized in Table 1.

Table 1
Characterization of Polyethylene Oxide-Poly(β -Benzyl L-Aspartate)
Block Copolymer and Micelles

Sample	PEO wt (%) ^a	Mn ^a	nPEO	nPBLA ^a	Particle size (nm) ^b	CMC (mg/L)
A-5-10	73.0	7000	110	9.0	18	10
A-5-20	53.3	9100	110	19	17	5.0
A-12-20	35.0	16000	270	20	21	10

a) determined by ¹H-NMR

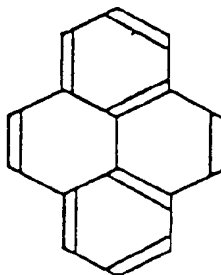
b) determined by dynamic light scattering (number-average)

Example 2 Formation of Micelles

The block copolymer synthesized in Example 1 was dissolved at a concentration of 0.01-0.1 % (w/v) in water or a suitable buffer. The formation of micelles in the thus obtained solutions was ascertained by measurement of distribution of particle size by dynamic light scattering. The result is set forth in FIG. 1. The particle size of micelle and critical micelle concentration are also shown in Table 1.

Example 3 Incorporation of Pyrene into Micelles

Pyrene of formula V:



V

is sparingly soluble in water so that a predetermined amount of pyrene was dissolved at acetone. After dissolved, acetone was removed under a nitrogen atmosphere, and a micelle solution of PEO-PBLA (A-5-10) in distilled water was added at a concentration shown in Table 1 to the pyrene.

1. Incorporation by Stirring

The above mixture was stirred for 2 days so that pyrene was incorporated into micelles.

2. Incorporation by Heating

The above mixture was heated at 80 °C for 2 hours so that pyrene was incorporated into micelles.

3. Incorporation by Ultrasonication

The above mixture was ultrasonicated for 15 seconds so that pyrene was incorporated into micelles.

4. Incorporation by Treatment with DMF for Making the PBLA segment swelled in the PEO-PBLA micelle.

As described above, acetone was removed from the pyrene solution. To the pyrene was added DMF in an amount of 30 % relative to the micelle solution to be added afterward. Then, a solution of PEO-PBLA in distilled water was then added in a concentration shown in Table 3 to the pyrene solution. After stirred for 15 hours, the solution was dialyzed in a dialysis tube Spectrapor 6 (cut off molecular weight = 1,000) against water. According to the above procedure, pyrene was incorporated into micelles.

As is evident from increases in the intensities of the fluorescence spectra of the heated sample shown in FIG. 2, the incorporation of pyrene into micelles was confirmed in every incorporation means. FIG. 3 shows a comparison between the amounts of pyrene incorporated into micelles, where the incorporation means by heating attains the amount of incorporated pyrene as approx. 250 times high as the amount of pyrene saturated in water. Table 2 shows the partition coefficient of pyrene into PEO-PBLA (A-5-10) micelle relative to water.

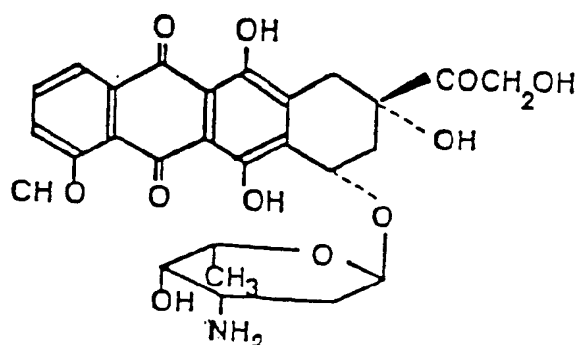
Table 2

Distribution Coefficient into Micelle Solution of Polyethylene Oxide-Poly(β -Benzyl L-Aspartate) Block Copolymer	
Means of Incorporating Pyrene	Distribution Coefficient (Kn)
Stirring	17000
Heating at 80 °C	21000
Ultrasonication	17000

Example 4

5 mg of adriamycin hydrochloride and 5 mg of PEO-PBLA (A-12-20) were added to 5 ml of 0.1 M Tris buffer, pH 9.1. Then, adriamycin was made miscible into micelles by stirring and ultrasonication.

Adriamycin is the compound of the following formula:



VI

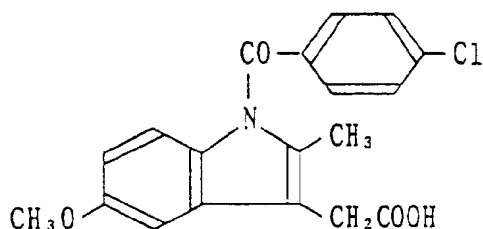
This compound itself does not dissolve in Tris buffer, pH 9.1, but can be completely dissolved according to the above procedure. As shown in FIG. 4, adriamycin appeared in gel-exclusion volume in GPC where the sample was monitored at 485 nm at which adriamycin shows characteristic absorption, and this indicates sufficient incorporation of adriamycin into micelles. In FIG. 4, elution volume is indicated as numerical values where 1.792, 3.292 and 9.300 mean micelles, a single polymer and unincorporated adriamycin, respectively.

Example 5

4.4 μ l triethylamine and 20 mg PEO-PBLA block copolymer (A-12-20) were added to a solution of 14 mg adriamycin hydrochloride in 4 ml DMF, and the mixture was stirred for 10 min. and then dialyzed for 15 hours against distilled water. Dynamic light scattering indicated that the sample thus obtained formed polymeric micelles with a weight-average diameter of 55 nm. FIG. 5 shows a gel permeation chromatogram of the polymeric micelles monitored at 485 nm. Adriamycin was incorporated in the micelles, as can be seen from its elution as micelles in gel exclusion volume (4.2-4.3 ml). FIG. 6 shows a gel permeation chromatogram of adriamycin incorporated in micelles after allowed to stand for 5 hours in the presence of 50%(V/V) fetal bovine serum. In FIG. 6, the peak (4.25 ml) eluted in gel exclusion volume and not present in the serum itself was not lowered in the presence of serum (Fig. 7), which indicates that adriamycin can be stably maintained in micells even in the presence of serum.

Example 6

15 mg of indomethacin of formula

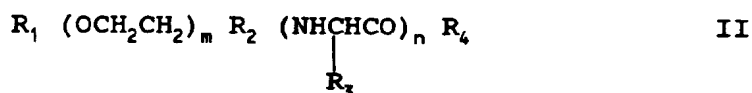


VII

as an anti-inflammatory drug was dissolved in 4 ml DMF, followed by addition of 20 mg of PEO-PBLA block copolymer (A-12-20). The mixture was stirred for 15 hours and dialyzed for 3 hours against 0.1 M phosphate buffer, pH 7.4, and then against water for 6 hours. The resulting sample was found to form polymeric micelles with a weight-average diameter of 56 nm, as determined by dynamic light scattering. FIG. 8 shows a gel permeation chromatogram monitored at 312 nm at which indomethacin shows characteristic absorption. The indomethacin was eluted as micelles in gel exclusion volume, indicating the incorporation of the indomethacin into micelles. 0.76 mg of indomethacin was found to be incorporated in the micelles from its adsorption monitored at 312 nm in a solvent of DMF/distilled water (7 : 3).

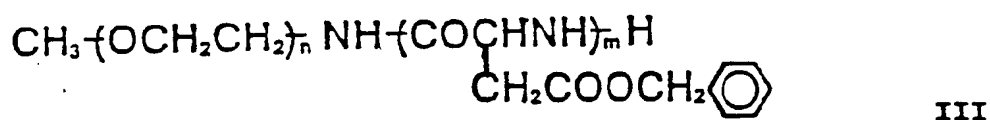
Claims

1. A polymeric micelle type drug composition which comprises at least one hydrophobic drug physically trapped in a drug carrier comprising a block copolymer represented by formula I or II:



wherein R₁ is hydrogen or an alkyl group having 1 to 20 carbon atoms, R₂ is NH, CO, R₆(CH₂)_qR₇ (in which R₆ represents OCO, OCONH, NHCO, NHCOO, NHCONH, CONH or COO, R₇ represents NH or CO, and q is 1 to 6), R₃ is hydrogen, an alkyl group having 1 to 20 carbon atoms, (CH₂)_pC₆H₅, (CH₂)_pCOOR₅ or CH₂CONHR₅ (in which p is 1 or 2, R₅ represents a C₁₋₂₀ alkyl group, a benzyl-substituted C₁₋₂₀ alkyl group or a benzyl group), R₄ is hydrogen, hydroxyl, RCO-, RNH- or RO- where R is an alkyl group having 1 to 20 carbon atoms, m is 4 to 2500, and n is 2 to 300.

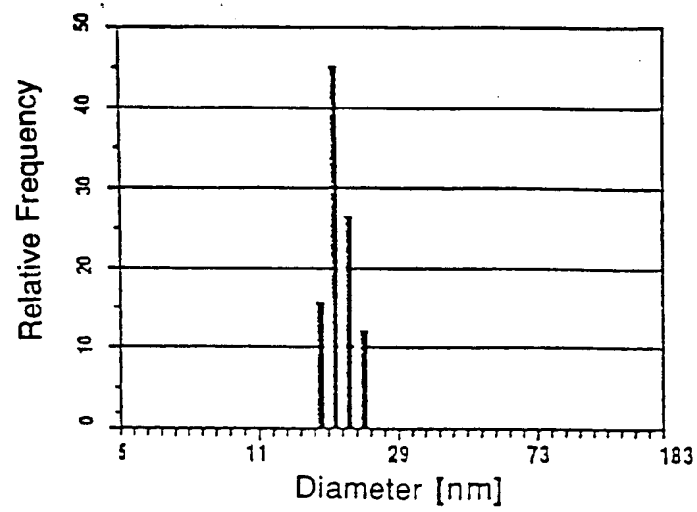
2. A composition according to claim 1, in which the block copolymer is a compound represented by formula III:



wherein m is 4 to 2500 and n is 2 to 300.

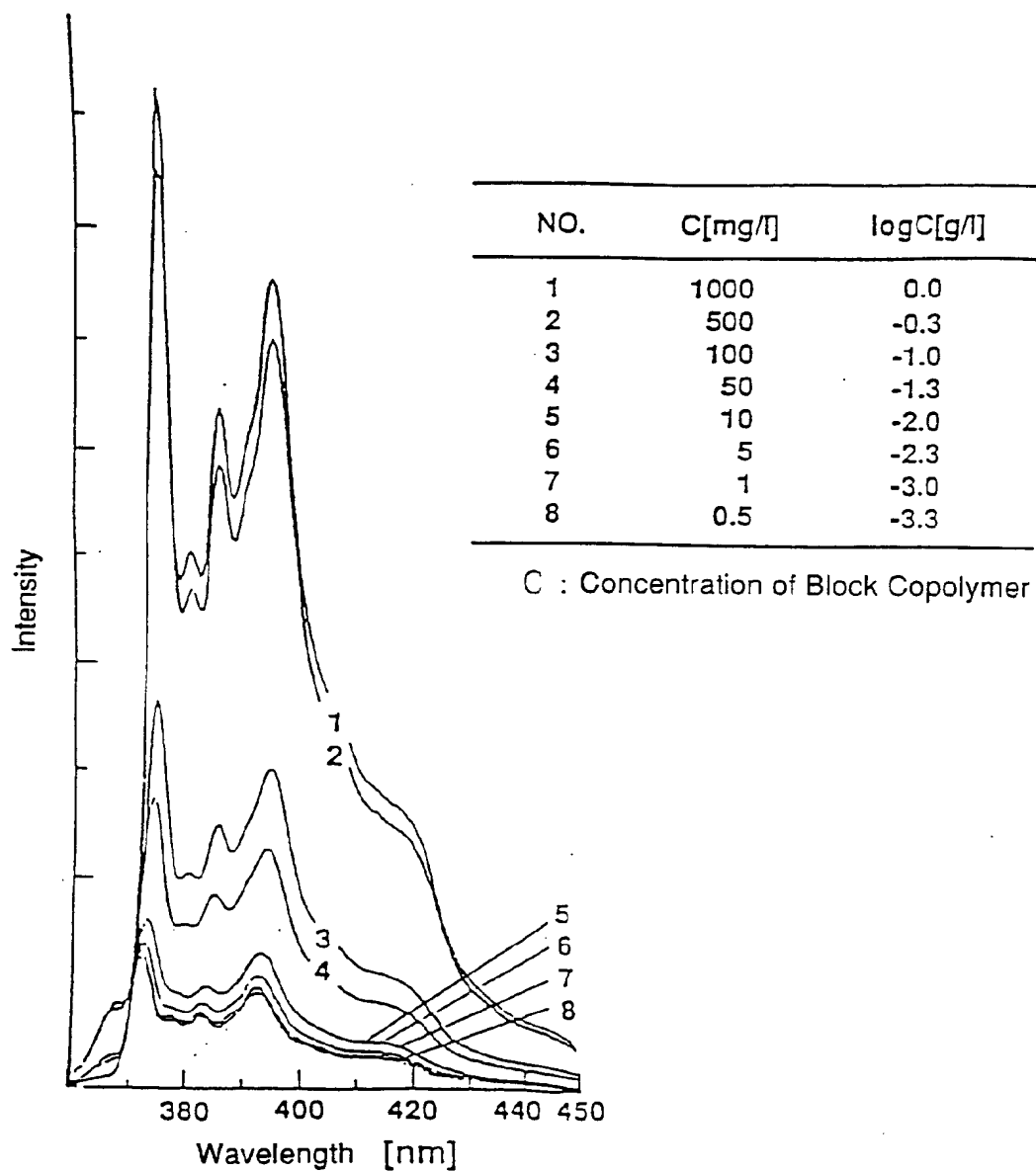
3. A composition according to claim 1 or 2, in which the hydrophobic drug is at least one of adriamycin, daunomycin, methotrexate, mitomycin C or indomethacin.
4. A composition according to claim 3 in which the hydrophobic drug is indomethacin or adriamycin.
5. A method for trapping hydrophobic drugs, which comprises the heating, ultrasonication or organic solvent treatment of hydrophobic drugs and drug carrier of formula I, II or III to physically trap said hydrophobic drugs in polymeric micelles comprising said drug carrier.

Fig. 1



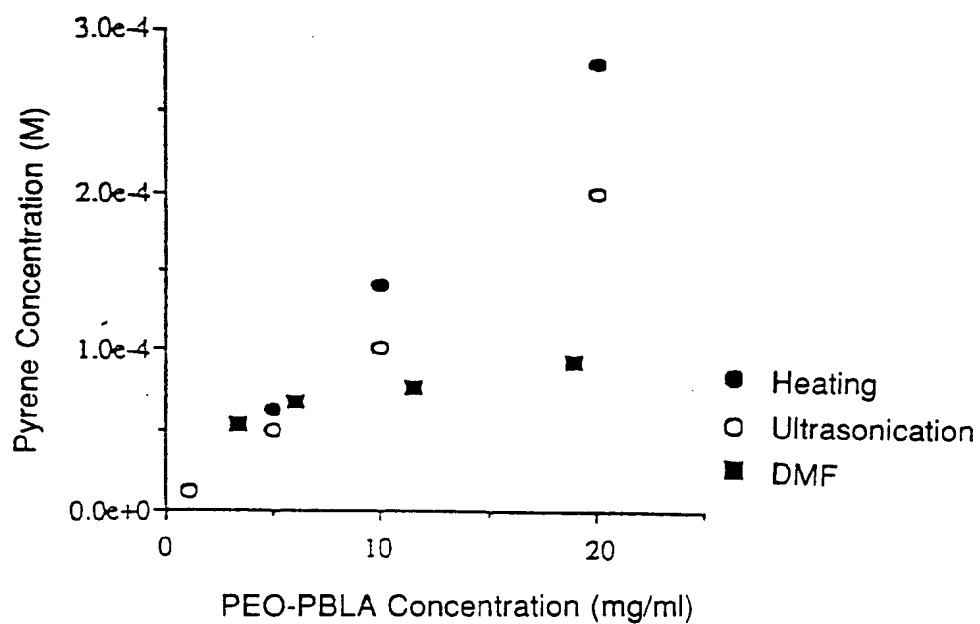
Particle Size Distribution of Block Copolymer
Micelles (A-5-10)

Fig. 2



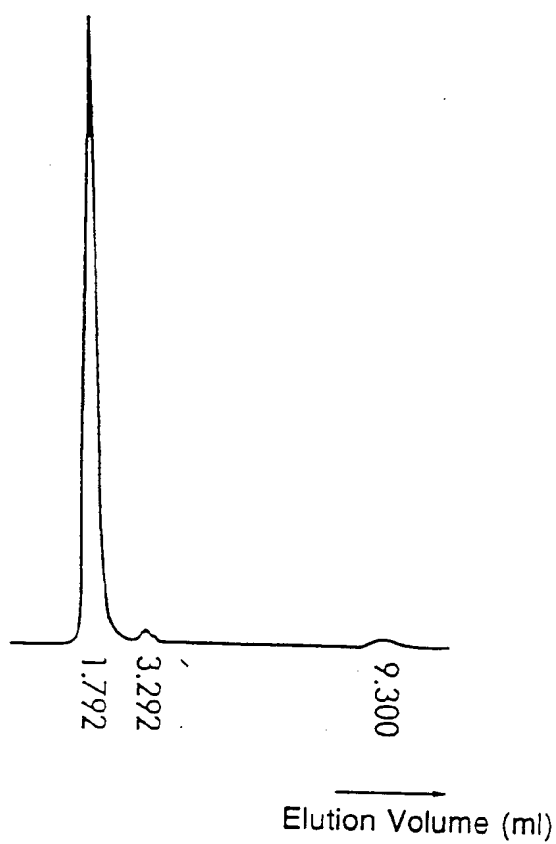
Fluorescence Spectra of Aqueous Pyrene Solution ($6 \times 10^{-7} \text{M}$)
 in the Presence of Block Copolymer Micelles(A-5-10)
 Excitation Wavelength: 339 nm

Fig. 3



Effect of Incorporation Means and Block Copolymer Concentration on the Amount of Pyrene Incorporated into Block Copolymer Micelles (A-5-10)

Fig. 4



Gel Permeation Chromatogram of Adriamycin-Incorporated Micelles

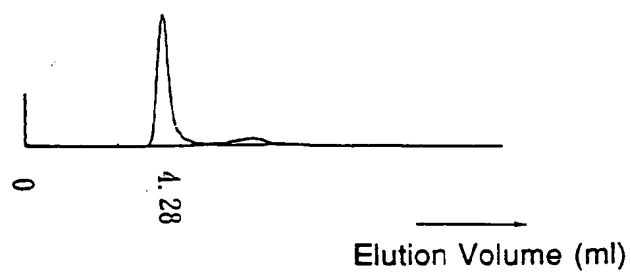
Column: Asahipak GS-510M

Eluent solvent: 0.1 M phosphate buffer, pH 7.4

Flow rate: 1.0 ml/min.

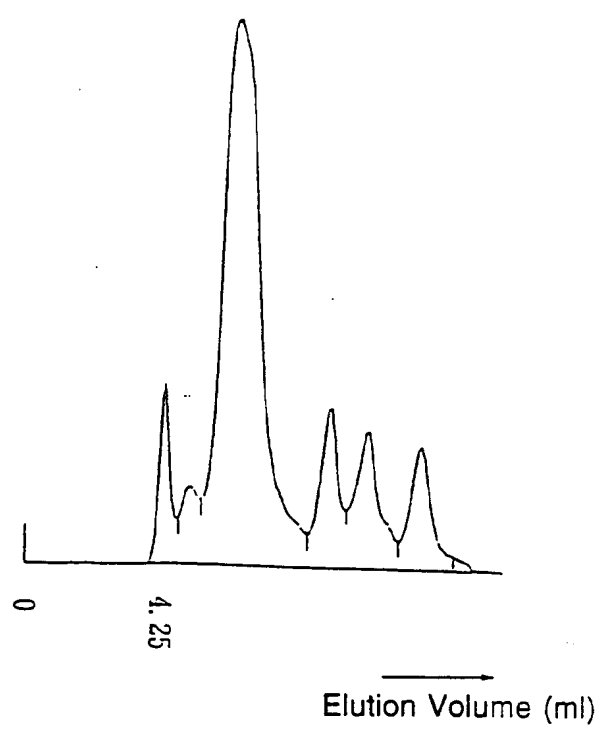
Adriamycin Concentration: 10 μ g/ml

Fig. 5



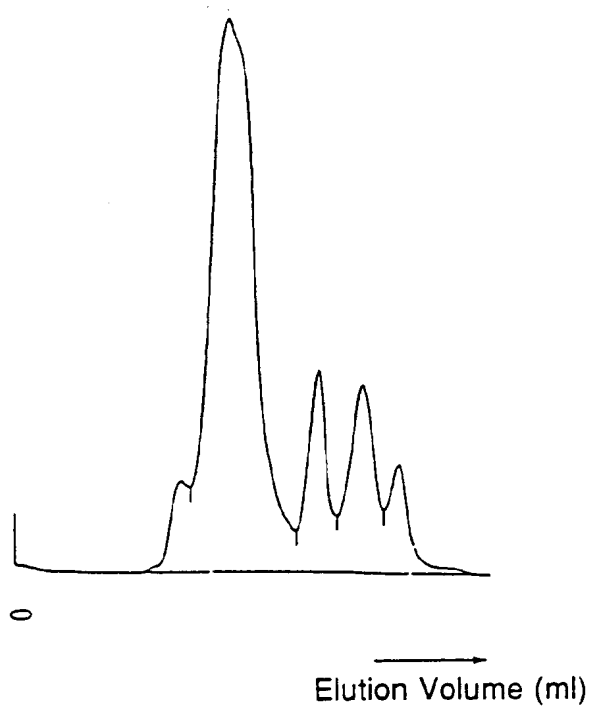
Column: Asahipak GS-520H
Eluent solvent: 0.1 M phosphate buffer, pH 7.4
Flow rate: 1.0 ml/min.
Detection: 485 nm

Fig. 6



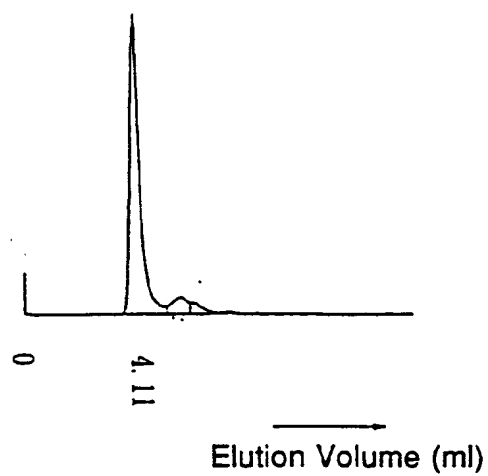
Column: Asahipak GS-520H
Eluent solvent: 0.1 M phosphate buffer, pH 7.4
Flow rate: 1.0 ml/min.
Detection: 485 nm

Fig. 7



Column: Asahipak GS-520H
Eluent solvent: 0.1 M phosphate buffer, pH 7.4
Flow rate: 1.0 ml/min.
Detection: 485 nm

Fig. 8



Column: Asahipak GS-520H
Eluent solvent: 0.1 M phosphate buffer, pH 7.4
Flow rate: 1.0 ml/min.
Detection: 312 nm